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HIGH GAIN, STEERABLE MULTIPLE BEAM ANTENNA SYSTEM

CROSS REFERENCE TO RELATED PATENT APPLICATION

This application is a continuation-in-part application of United States Patent Application No.10/673,033 filed September 27, 2003, now pending, which is incorporated by reference herein.

BACKGROUND OF THE INVENTION

In wireless communications efficient communications can be greatly facilitated by much improved and novel antenna systems. Thus, there is a long standing need in the wireless communications and antenna art for antennas that can provide high-gain, antennas that provide for multi-beams, and antennas that can provide 360 degree radiation.

BRIEF DESCRIPTION OF THE INVENTION

The present invention is a multi-beam antenna system that can be used in microwave frequency applications between 1 GHz and 100 GHz. The multi-beam antenna system covers four 90° sectors for full 360° coverage. Each 90° sector is covered with at least 1 narrow steerable transmit (TX) and 1 narrow steerable receive (RX) beam. The beams are steered in the azimuth dimension.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present invention may be had by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

FIGURE 1 is a plan view diagram that illustrates a multi-beam antenna system in accordance with the present invention;

FIGURE 2 is a diagram illustrating in greater detail one way a controller can be used to control the multi-beam antenna system shown in FIGURE 1;

FIGURE 3 is a diagram illustrating in greater detail the components of a single aperture that can be used within the multi-beam antenna system shown in FIGURE 1;

FIGURE 4 is a diagram illustrating in greater detail the components of a beam former that can be used within the multi-beam antenna system shown in FIGURE 1;

FIGURE 5 is a diagram illustrating in greater detail the components of a secondary power combiner/splitter and

the radiating elements that can be used within the multi-beam antenna system shown in FIGURE 1;

FIGURES 6A and 6B are diagrams that illustrate different feed structures that can be used in the primary power combiner/splitter shown in FIGURE 4 and the secondary power combiners/splitters shown in FIGURE 5;

FIGURE 7 is a diagram that illustrates how the beam former shown in FIGURE 4 can be connected to the centre-series feed secondary power combiner/splitter shown in FIGURES 5 and 6B;

FIGURE 8 is a diagram that illustrates one way to package the multi-beam antenna system shown in FIGURE 1;

FIGURES 9A and 9B are diagrams of another embodiment of the multi-beam antenna system shown in FIGURE 1;

FIGURE 10 is a diagram of one of the four radiation element array panels used in the multi-beam antenna system shown in FIGURES 9A and 9B; and

FIGURE 11 is a diagram of a controller implemented within the multi-beam antenna system shown in FIGURES 9A and 9B.

DETAILED DESCRIPTION OF THE DRAWINGS

The multi-beam antenna system 100 includes four pairs of independent TX (transmit) and RX (receive) apertures 110 that may be arranged into a square formation as shown in FIGURE 1 (see also FIGURES 8 and 9). Each pair of TX and RX apertures 110 emits a pair of TX and RX radiation beams 112 that cover one 90° wide sector, so that the multi-beam antenna system 100 can cover the full 360° range.

The multi-beam antenna system 100 also includes a controller 115 (e.g., embedded controller 115) shown in FIGURE 2 that performs all of the tasks related to pointing the radiation beams 112. The controller 115 performs the following functions:

- Receive and execute antenna commands 202
- Control the RF switches 204.
- Adjust the tunable phase shifters 206

In particular, the controller 115 receives the antenna commands 202 from a radio's media access controller (MAC) 208 and executes the commands 202 in order to point any of the eight radiation beams 112 to a specific azimuth setting. The radiation beam 112 pointing functions are carried out through the use of electronic RF switches 204 and phase shifters 206. The RF switches 204 are used to select a particular aperture 110 or antenna quadrant while the phase shifters 206 on each of the four sides of the multi-beam antenna system 100 are adjusted to achieve

incremental steering of the radiation beams 112. Alternatively, the multi-beam antenna system 100 can be fed by four separate transceiver systems, allowing for four simultaneous RX beams 112 and four simultaneous TX beams 112.

Each TX and RX aperture 100 as shown in FIGURE 3 includes multiple rows and columns of radiating elements 302. The radiating elements 302 in each column are connected together via microwave transmission lines in a column secondary power splitter 304 (in the RX aperture 100) or column secondary power combiner 304 (in the TX aperture 100). The secondary power splitter/combiners 304 are connected to a beam former 306 that steers the radiation beam 112 in one dimension, which in the preferred embodiment is the azimuth direction. Above 10 GHz, the transmission lines and/or secondary power combiners/splitters 304 are usually realized in waveguides to minimize loss, but microstrip or stripline transmission lines and power combiner/splitters can be used up to about 30GHz. Waveguide transmission lines and power combiners/splitters can also be used below 10GHz, but the structure can become quite bulky. Co-axial transmission lines are also practical below about 3GHz. With the use of microstrip, striplines or co-axial lines, wide bandwidth corporate feed structures are easily realizable, such a structure is shown in FIGURE 6A. Waveguide corporate feed structures are very bulky, requiring significant amounts of volume. For this reason, series fed waveguide structures

are used instead when the operating bandwidth is narrow (less than 5% of the operating frequency), as shown in FIGURE 6B. The series fed waveguide structure is used in the preferred embodiment of the primary power combiner/splitter 308 (see FIGURE 4) and the secondary power combiners/splitters 304 (see FIGURE 5).

As shown in FIGURE 4, the beam former 306 includes a primary power combiner/splitter 308 (e.g., centre fed waveguide 308) which distributes/collects power in a serial manner to/from the row of phase shifters 206. The phase shifters 206 in turn feed the column secondary power combiners/splitters 304 having the form of secondary waveguides fed at their respective centres, which finally distribute power again in a serial fashion to the radiating elements 302 (e.g., antenna elements 302)(see FIGURE 3). This waveguide feed arrangement is in particular the most practical for Ku-band and Ka band applications since it is compact. In addition, this waveguide feed arrangement ensures low loss power transmission.

The beam former 306 as depicted in FIGURE 4 has a co-axial cable 310 feeding the primary power combiner/splitter 308 (e.g., primary waveguide 308) at its centre. The primary waveguide 308 is coupled to a row of phase shifters 206 via broad wall slots 312 that are spaced roughly at half guided-wavelengths along the length of the primary waveguide 308. The spacing is not important, since the phase shifters 206 can be used to correct any phase differences, therefore it can be adjusted to match the

widths of the secondary waveguides 304 (e.g., secondary power combiners/splitters 304)(see FIGURE 7). The phase shifters 206 shown here are slotline phase shifters 206 where the slot gaps are loaded with a voltage tunable ferroelectric material. In the preferred embodiment, the voltage tunable ferroelectric material is made and sold under the name of Parascan™ material by Paratek Microwave, Inc. A bias voltage applied across the slotline gap is used to control the dielectric constant of the voltage tunable material, and hence the velocity of propagation in the slotline. The phase shifters 206 are designed with enough length to vary at least one wavelength in electrical length over the possible bias voltage range, thereby creating 360° of phase shift. The slotline gap width can be varied along its length, to create a non-uniform loaded slotline. This technique, which is done to allow a low biasing voltage to be used without increasing metallic current losses, is described in greater detail in U.S. Patent Application Serial No. 10/199,724 entitled "A Tunable Electromagnetic Transmission Structure for Effecting Coupling of Electromagnetic Signals" that was filed August 19, 2002. The contents of this patent application are hereby incorporated by reference herein.

Each phase shifter 206 in the beam former 306 couples to the centre of a secondary waveguide 304 (e.g., secondary power combiner/splitter 304) as shown in FIGURE 5. The secondary waveguide 304 couples to a column of the antenna elements 302 via broad wall slots 314 along its length.

The slots 314 are spaced at half a guided wavelength apart, alternating on different sides of the waveguide's centre line. This ensures that the slots 314 are excited in series and in phase, since the broad wall current distribution flows away from the centre line of the secondary waveguide 304. The antenna elements 302 shown are stacked rectangular patches. These can be of any other shape (elliptical, polygon) as long as the radiated field exhibits polarization purity and power can be transmitted/received into/from space efficiently. Other types of antenna elements 302 can be used such as Vivaldi elements. Alternatively, the slots 314 themselves can be used as radiating elements 302. FIGURE 7 is another diagram that illustrates how the beam former 306 can be connected to multiple centre-series feed secondary power combiners/splitters 304.

Referring to FIGURE 8, there is a diagram that illustrates one way to package the multi-beam antenna system 100 shown in FIGURE 1. The multi-beam antenna system 100 scans 1-D beam(s) 112 (narrow in azimuth with scanning and narrow in elevation with fixed cosecant squared null fill) anywhere within 360 degrees. The package shown is a truncated pyramid where each face or aperture 110 contains individual transmit and receive arrays. All of the components both RF elements (dividers, combiners, switches, phase shifters, amplifiers...) and control elements (power supply...) are contained within the package.

One embodiment of the multi-beam antenna system 100 may have the following capabilities shown in TABLE #1:

TABLE #1

	Transmit	Receive
Frequency	14.7-14.9 GHz	15.1-15.3 GHz
Polarization	RHCP	LHCP
Beam Steering	360 degree Azimuth (fixed beam in Elevation) each single panel providing +/- 45 degree azimuth scan	
Beamwidth Azimuth half-power	5 degree Az	
Beamwidth Elevation half-power	5 degree El--shaped with cosecant squared null fill in the up direction	
Beam scan/switching time	< 10 ms (based on 20 mrad/sec tracking requirement)	
Maximum incoming power	20W	20W
Antenna gain	24 dBi	24 dBi
Antenna EIRP	37 dBW per beam	-
Front-to-Back ration (F/B)	>20dB	>20dB
Return Loss	<-14dB (1.5:1 VSWR)	<-14dB (1.5:1 VSWR)
Impedance	50Ω	50Ω
Polarity discrimination	> 20dB	
Antenna Size	~36"x36" footprint by ~16" high	

Referring to FIGURES 9-11, there are several diagrams illustrating another embodiment of the multi-beam antenna system shown in FIGURE 1.

In this embodiment, an active receive only multi-beam system 100' is described and shown whereby one or more of four array panels 110' is selected by a RF switching system 204'. As shown, the array panels 110' are connected via the RF switching system 204' to a 4-port phase shifter matrix 206' which includes 4 beam formers 306'. It should be appreciated that there could be M-phase shifter matrices 206' and M-beamformers 306'. Each beamformer 306' has 1 output port and N input ports, where N corresponds to the number of columns of antenna elements 302 in the corresponding array panel 110' (see FIGURE 3). The M beamformers 306' allow the array panels 110' to simultaneously receive N radiation beams 112' (not shown). This is done by connecting input port n (n=1,2,...,N) of each of the M beamformers 306' to an output of a low noise amplifier (LNA) 902 connected to column power combiner 304' number n (n=1,2,...,N), which feeds column no. n of antenna elements 302' in the corresponding array panel 110'. M receivers 904 are connected to the M output ports of the M beamformers 306'. It should be appreciated that in another embodiment 4 parallel systems of M receivers 904 and M beamformers 306' can be connected to the 4 array panels 110' eliminating the need for the RF switching system 204. It should also be appreciated that a multi-beam transmit system can be constructed by reversing the direction of the

LNAa 902 and connecting the beamformers 306' to transmitters (not shown) instead of to receivers 904. In yet another embodiment each side of the square of array panels 110' can be constructed to house 1 TX and 1 RX aperture 110' to form a full multi-beam transceiver system 100 that is capable of handling M simultaneous beams per aperture 110'. Thus, the main difference between the embodiment shown in FIGURE 9A and that shown in FIGURE 1, is that the number of simultaneous beams per antenna array aperture 110 has been increased from 1 to a multitude of M beams.

FIGURE 9B shows a further addition/improvement to the antenna system 100' whereby each antenna array element 302' is dual polarized. FIGURE 9B shows microstrip feed power combiners/splitters 304' feeding array columns consisting of 2 patch-type elements 302' (only two elements per column are shown for simplicity, but this can be increased/reduced to any arbitrary number). Since each of the dual polarized columns of antenna elements 302' now has two isolated ports representing two orthogonal polarizations, a second P-port phase shifter matrix connected to P receivers/transmitters can be used to feed the additional polarization. Thus, each array aperture is capable of handling M simultaneous beams of one polarization, and P simultaneous beams of the orthogonal polarization. Figure 10 shows the position of the LNA's 902′ connected to each column of array elements 1010. Each LNA 902′ is connected via a band pass filter 1005 to the array column 1010 to protect the LNA 902′ from

out of band high power signals. Figure 11 shows how the controller 115 of Figure 2 will be connected to the different components of the beamformers 306'. Components may include V/H Polar Switches 1105, Panel Beam 1110, tunable bandpass filter 1115 and phase shifters. 1120.

The phase shifters 206 in the preferred embodiment may incorporate a voltage tunable ferroelectric material comprising Barium-Strontium Titanate, $Ba_xSr_{1-x}TiO_3$ (BSTO), where x can range from zero to one, or BSTO-composite ceramics. Examples of such BSTO composites include, but are not limited to: BSTO--MgO, BSTO--$MgAl_2O_4$, BSTO--$CaTiO_3$, BSTO--$MgTiO_3$, BSTO--$MgSrZrTiO_6$, and combinations thereof.

The following is a list of some of the patents which discuss different aspects and capabilities of the voltage tunable ferroelectric material all of which are incorporated herein by reference: U.S. Patent Nos. 5,312,790; 5,427,988; 5,486,491; 5,635,434; 5,830,591; 5,846,893; 5,766,697; 5,693,429 and 5,635,433.

The phase shifters 206 can be configured as anyone of the phase shifters disclosed in U.S. Patent Nos. 6,377,217; 6,621,377; 6,538,603; and 6,590,468. Or disclosed in U.S. Patent Application Serial Nos. 09/644,019 (August 22, 2000); 09/838,483 (April 19, 2001); 10/097,319 (March 14, 2002); 09/931,503 (August 16, 2001); and 10/226,746 (August 27, 2002). The contents of these patents and patent applications are hereby incorporated by reference herein.

The multi-beam antenna system 100 enhances the spatial and frequency agility of communication networks--at the

antenna and the receiver system. Further, the multi-beam antenna system 100 can be used in mobile ad-hoc networks.

While the present invention has been described in terms of its preferred embodiments, it will be apparent to those skilled in the art that various changes can be made to the disclosed embodiments without departing from the scope of the invention as set forth in the following claims.